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THESIS

MODELING SHIP AIR CONDITIONING MAINTENANCE COSTS USING THE INTEGRATED CONDITION ASSESSMENT SYSTEM (ICAS)

by

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December 2002

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The United States Navy operates in seas such as the Arabian Gulf, where water temperatures can exceed 90 degrees and air temperatures surpass 95 degrees. An intuitive link exists between these higher operating temperatures and an increased demand on shipboard Air Conditioning (A/C) plants. Increased plant usage, in turn, causes higher A/C plant maintenance costs. To build an accurate cost model for shipboard Air Conditioning plants, this thesis examines the relationship between seawater temperature, A/C plant run-hours, and A/C plant maintenance costs. Data generated by the Integrated Condition Assessment System (ICAS) were used to test a correlation between these factors for TICONDEROGA, ARLEIGH BURKE, and OLIVER HAZARD PERRY class ships. The results indicate that although seawater temperature is a statistically significant factor in determining A/C plant use, plant use is not a statistically significant driver of maintenance costs. Although the findings discourage further research into this area, the methodology developed for using ICAS data may be applied to other shipboard systems.

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MODELING SHIP AIR CONDITIONING MAINTENANCE COSTS USING THE INTEGRATED CONDITION ASSESSMENT SYSTEM (ICAS)

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ABSTRACT

The United States Navy operates in seas such as the Arabian Gulf, where water temperatures can exceed 90 degrees and air temperatures surpass 95 degrees. An intuitive link exists between these higher operating temperatures and an increased demand on shipboard Air Conditioning (A/C) plants. Increased plant usage, in turn, causes higher A/C plant maintenance costs. To build an accurate cost model for shipboard Air Conditioning plants, this thesis examines the relationship between seawater temperature, A/C plant run-hours, and A/C plant maintenance costs. Data generated by the Integrated Condition Assessment System (ICAS) were used to test a correlation between these factors for TICONDEROGA, ARLEIGH BURKE, and OLIVER HAZARD PERRY class ships. The results indicate that although seawater temperature is a statistically significant factor in determining A/C plant use, plant use is not a statistically significant driver of maintenance costs. Although the findings discourage further research into this area, the methodology developed for using ICAS data may be applied to other shipboard systems.

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I. INTRODUCTION

A. COST MODELS

The United States Navy maintains a continuous presence in areas such as the Arabian Gulf and the Mediterranean Sea. This forward presence is vital to promoting peace and stability in these regions, and is also a crucial lever in enforcing the United Nations sanctions against Iraq. The U.S. Naval Service will likely remain engaged in these regions for the foreseeable future. The Arabian Gulf is of particular concern because of the value of the oil resources located there and because it presents an extreme operating environment to naval vessels. Although operations in the Arabian Gulf were once considered to be contingent in nature, they are now viewed as being routine. Thus, the costs for operations in the area must now be included in the regular budget cycle for incorporation into the Operations and Maintenance (O&M) accounts (Emerson, 2001).

Naval budget planners are continually challenged to accurately forecast maintenance costs. Improved cost models would allow for a more efficient allocation of O&M dollars. For example, rather than evenly allocating maintenance funds across all ships in a squadron, these funds could be distributed by a formula that takes into account the planned operational schedule of the vessels in the squadron. Factors such as Operating Area (OPAREA) environment, deployment length, and transit speed would be used to develop a cost estimate. In the case of shipboard Air Conditioning (A/C) and other major subsystems, an improved cost model would use, as an input, the actual usage of the equipment. This approach would capture the variability of maintenance costs associated with different OPAREAs. A more accurate and defensible cost model would prove useful for budgetary planning and would also make individual subsystem support costs more visible.

This research uses Integrated Condition Assessment (ICAS) data to identify the relationship between A/C plant usage and plant maintenance costs. This model will capture the intuitive variability of maintenance costs with A/C plant usage, and will also identify the association between plant usage and OPAREA as defined by air or seawater

temperature. The resulting model may be applied to individual hulls and used to predict costs based on projected plant usage.

B. BACKGROUND

The United States Navy frequently operates in areas of the world where ambient air and seawater temperatures are significantly higher than those in the North Atlantic or Western Pacific oceans. Specifically, the Mediterranean Sea and the Arabian Gulf warm to over 80 degrees (F) and 90 degrees (F), respectively, during the warmest part of the year. Intuitively, on average, shipboard A/C plants log more use when a ship operates in warm climates. However, despite the easily verifiable decrease in the thermodynamic efficiency of the A/C plants, to date the actual correlation of operating environment as indicated by air or seawater temperature and A/C plant usage has remained a matter of intuition. The development of such a link has historically been hampered by a shortage of consolidated information on A/C plant usage.

U.S. Navy ships are required to monitor performance trends in machinery and equipment to improve predictions on the need for corrective maintenance. For an A/C plant, the information logged includes seawater inlet temperature and A/C plant status (whether or not it is running). Until 1996, the logging of equipment parameters and performance trends was done manually via paper logsheets. These logsheets are retained locally and are structured to contain one day's worth of readings. Equipment logsheets are not standardized for a given class of ship but rather are locally generated documents. Further, logsheet data are normally retained onboard only and not consolidated by ship class or operating squadron. Using this system, determining the actual number of hours that a single A/C plant was run on a particular ship requires a careful and detailed review of manual logsheets covering the desired span of time. The problem becomes progressively more complicated for a review of all A/C plants on a single ship. For multiple ships, or a fleet-wide initiative, such reviews are prohibitively time-intensive.

ICAS was introduced into the fleet in 1995. This system was developed to automate the collection and synthesis of auxiliary equipment and propulsion plant parameters, the goal being to ease performance trend analysis. With improved and timely equipment trend analysis, the Navy expects to generate maintenance cost savings by

focusing maintenance efforts and resources only on equipment nearing a recognizable failure, a philosophy called Condition Based Maintenance (CBM) (Chief of Naval Operations NTP S-30-0001, 2001). This approach contrasts with the current method of preventative maintenance, under which resources are spread equally over all similar equipment using a calendar driven system. Currently, 97 ships are equipped with ICAS (Naval Sea Systems Command, 2002).

ICAS configuration varies by ship class. Generally, a watchstander uses a hand-held digital device to input certain plant parameters and periodically downloads the data into an ICAS terminal. On some ship classes, ICAS also has the capability of automatically recording auxiliary and propulsion plant parameters without the input of a watchstander. The mix of manual and automatic recording varies from highly automated (ARLEIGH BURKE class destroyers), to a purely manual process (OLIVER HAZARD PERRY class frigates). Atlantic Fleet ICAS data are periodically forwarded to the Fleet Technical Support Center Atlantic (FTSCLANT) for consolidation (Commander Naval Surface Forces Atlantic, 1999). Fleet Technical Support Center Pacific (FTSCPAC) performs the same function for the Pacific Fleet (Commander Naval Surface Forces Pacific, 2001). The consolidated data are then sent to the Naval Sea Systems Command for permanent storage and inclusion in the Maintenance Engineering Library Server (MELS). The MELS database is available for download and analysis via the Internet. However, because ICAS installation is ongoing, most ships have had the system in use for a period of less than two years.

Because ICAS data are centrally consolidated and easily convert to spreadsheet-ready formats, the system provides previously unavailable information useful in determining the actual number of hours an A/C plant was run over a given span of time, along with seawater temperature for the time period. The results of this analysis can be used to investigate the relationship between seawater temperature and workload on the A/C plants, although the results may not be representative because of the limited time that ICAS has been installed on those ships with the system. When combined with meaningful cost data for the same period of time a quantifiable relationship between operating area (as delineated by seawater temperature) and maintenance costs may emerge.

Chapter II of this study proposes a cost model for A/C plants, and develops a methodology to extract the needed run-hour and seawater temperature information from ICAS data. The results of the above analysis, when combined with available cost data complete the model.

II. METHODOLOGY

A. SAMPLE

1. Ship Classes

The Maintenance Engineering Library Server (MELS) included data for TICONDEROGA (CG-47) class cruisers, ARLEIGH BURKE (DDG-51) class destroyers, SPRUANCE (DD-963) class destroyers, and OLIVER HAZARD PERRY (FFG-7) class frigates, among others. The researcher chose the CG-47, DDG-51, and FFG-7 classes for inclusion in the study because these vessels share operating characteristics and normally experience similar seawater conditions as part of a group or task force. The DD-963 ships also share these characteristics. However, all SPRUANCE class destroyers will be decommissioned by 2006 (Chief of Naval Operations, 2000), making future efforts at research involving them more difficult. This outlook contrasts with that of the other three classes, all of which are projected to remain in the nation's inventory for the foreseeable future.

2. Number of Ships Used in the Study

The MELS contains data on 55 ships. The breadth of MELS coverage regularly expands as more vessels acquire ICAS and computing resources become available. Of the 55 ships with data in MELS, this study selected 13 DDG-51, 6 CG-47, and 5 FFG-7 class ships. Time and resource limitations precluded using all 55 ships present in MELS for the study. The numbers of each ship class were chosen to reflect the near-term makeup of the fleet at the completion of the DDG-51 series production (Surface Warfare Division, 2002). At program completion, there will be 57 DDG-51 destroyers (projected), approximately twice as many than either FFG-7 or CG-47 ships. Conversely, the individual hulls within each class used in the study were chosen at random from those available in MELS. This constricted data pool yielded 175,227 individual ICAS log entries for analysis.

3. Sources of Data

a. Air Conditioning System Operating Data

The Maintenance Engineering Library Server (MELS) stores ICAS-generated information for all systems normally monitored by in-plant watchstanders, which includes parameters for shipboard A/C plants. Within MELS, information is grouped by ship. For each ship, a user can view all available entries for a specific subsystem, such as for an individual A/C plant. Below the subsystem level, data for a parameter of a subsystem may be viewed for trend analysis within MELS or converted to Comma Separated Value (CSV) format for export to spreadsheet applications. For A/C plants, there are, on average, over 20 selectable parameters. These include compressor discharge pressure, compressor motor amperage, condenser discharge pressure, and seawater inlet temperature. For this study, all A/C plant operating data, to include run-hours and seawater inlet temperature, were queried by ship, and then for each individual A/C plant installed aboard a ship. All available entries for a given A/C plant were used in this research.

b. Cost Data

All Planned Maintenance System (PMS) items performed by a ship's crew that require a requisitioning of parts to complete, or that must be deferred, are documented in the Current Ship's Maintenance Project (CSMP). Similarly, corrective maintenance actions and maintenance performed by an Intermediate or Depot level facility are also documented in the CSMP (Chief of Naval Operations, 1994). Periodically, ships must forward a record of completed maintenance actions to the Naval Sea Logistics Center (NSLC) via the Type Commanders (TYCOM).

The NSLC maintains records of reported Organizational and Intermediate level maintenance for all ships that operate in accordance with the Planned Maintenance System. Maintenance actions related to the nuclear power plants on aircraft carriers and submarines are governed by a separate authority and do not fall under the PMS system (Chief of Naval Operations, 1994). The maintenance information is accessible via the Ship Material Condition Metrics (SMCM) interface.

SMCM can be queried for the desired level of detail. Organizational and Intermediate level Maintenance costs can be found for an entire ship, or ship class, for any major subsystem covered by the PMS program. Users can research the maintenance costs for a specific subsystem by specifying that subsystem's Allowance Part List (APL) number, system nomenclature, or, for a group of related subsystems, by using the Equipment Identification Code (EIC). An individual ship can also be specified as a major subsystem, yielding the total maintenance costs reported for that ship.

Cost queries can be applied simultaneously to an entire class of ships, or fleetwide. Users may also track costs for unique groups of ships, such as a battlegroups. Queries can be specified to include costs within a moving timeframe of user-defined width or within a fixed timeframe. The smallest time increment used in SMCM is one month.

The available data included the cost of parts used in repairs and maintenance, as well as the man-hours required to complete each maintenance action. Man-hours were allotted a cost estimate of \$37.50 per hour at the Organizational level, and \$41.50 per hour for maintenance at the Intermediate level (Naval Sea Center for Logistics SMCM, 2002).

B. RESEARCH DESIGN

1. Model

An intuitive link exists between ambient seawater temperature and Air Conditioning plant usage. Seawater temperature, in turn, is related to ambient air temperature (Emerson, 2001). Specifically, as ambient air temperature rises, temperatures within the skin of a ship also rise. This temperature increase causes higher demand for A/C plant services, resulting in greater use of the plants. This intuitive link also extends to cost, with A/C plant usage acting as the primary cost driver for maintenance and repairs. The relationship is illustrated in Figure 1. .

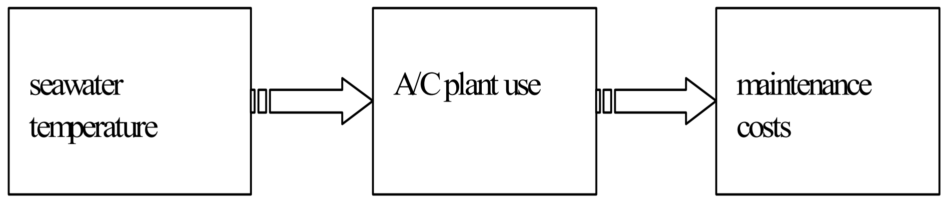

Figure 1. An illustration of the thesis model.

2. Inputs to the Model

a. Air Conditioning Plant Run-time and Seawater Inlet Temperature

In MELS, the ICAS data for a specific A/C plant was stored in the form of a sequential table of recorded parameters, sorted by the date and time of the log entry. As is standard practice with paper logs, ICAS log entries were made only if the monitored equipment was online (Leonard, 2002). If online, then log entries for the equipment were made at periodic intervals. For A/C plants, this interval was two hours. There were nominally twelve log entries for an A/C plant that was kept running for a 24-hour day. For this research, the A/C plant was considered to be continually running for any two-hour period between consecutive log readings (Krooner, 2002).

For each ship considered in the analysis, all available log entries for seawater inlet temperature, for all A/C plants, were retrieved from MELS. Each entry, or datum, consisted of the date and time of the log entry and the seawater inlet temperature. Each datum thus contained two essential bits of information: 1) The online status of the A/C plant at the time of the log entry, and 2) seawater inlet temperature to the A/C plant at the time of the entry.

All A/C plant data for an individual ship were grouped and organized chronologically. The data were then analyzed to determine how long each A/C plant was run on a particular day. This latter step was followed by a search for daily entries with total run-hours fewer than 24. Any such entries were removed from the dataset because at least one A/C plant is continuously running on a ship that is at sea or inport, due to vital shipboard equipment requiring cooling by these systems. Thus, the minimum daily A/C run-hour total was 24.

Concurrent with the A/C run-hour analysis, the seawater inlet temperature data was used to calculate a daily average for seawater temperature. The practical limits for seawater temperature were established at 100 degrees (F) and 20 degrees (F). Seawater temperatures beyond these limits are considered highly improbable.

Figure 2. shows the final form of the above analysis for an ARLEIGH BURKE class destroyer.

DATE	A/C1 HRS	A/C2 HRS	A/C3 HRS	A/C4 HRS	TOT HRS	AVG SW TEMP
12/10/2001	0	20	14	10	44	80.67
12/11/2001	2	18	20	2	42	81.50
12/12/2001	2	22	20	2	46	81.48
12/13/2001	2	18	20	2	42	81.34
12/14/2001	14	24	10	0	48	83.43
12/15/2001	24	20	0	0	44	84.67
12/16/2001	22	16	0	0	38	84.10
12/17/2001	22	22	2	0	46	83.58
12/18/2001	20	22	2	0	44	83.35
12/19/2001	22	14	8	0	44	82.22
12/20/2001	20	2	24	0	46	83.10
12/21/2001	24	0	24	0	48	83.42
12/22/2001	16	2	22	0	40	83.52
12/23/2001	18	0	18	0	36	82.06

Figure 2. Sample output of A/C run-hours and seawater temperature data.

b. Maintenance Costs

The A/C plant run-time analysis yielded an inclusive date range over which the respective ICAS data were collected. This date range was used to query the NSLC database for combined maintenance costs (Organizational and Intermediate level), to include parts and labor over the relevant time-period measured in months. This approach required a unique query for each ship. Daily cost data were not available. Figure 3. gives an example of the final form of the cost data for a PERRY class frigate.

Month	COST	HOURS
Jul-02	$0	176
Aug-02	$8,250	970
Sep-02	$2,574	818
Oct-02	$0	574
Nov-02	$0	584
Dec-02	$0	536
Jan-02	$6,656	744
Feb-02	$0	772
Mar-02	$0	608
Apr-02	$1,875	72

Figure 3. Sample output of maintenance cost and usage analysis.

Costs were categorized according to Allowance Parts List (APL) number. Generally, every part or major subsystem that is supported by the naval logistics system has a unique APL that is used to identify the item. All jobs and work orders entered into a ship's CSMP require an APL to identify the subsystem undergoing maintenance. The SMCM interface allows queries by multiple APL's for individual hulls, all ships within a class, or fleet-wide. For this research, cost queries were made using APL's that identified each of the A/C plants aboard a ship at the major subsystem level. The needed APL's were initially identified using the Integrated Class Maintenance Plan (ICMP) utility (Naval Sea Center for Logistics ICMP, 2002). The appropriateness of the identified APL's was verified by descriptions contained in the Hull, Mechanical, and Electrical Equipment Data Research System (HEDRS) database (Naval Sea Center for Logistics HEDRS, 2002). A listing of APL's used to research costs for each ship class is contained in Appendix A.

3. Level of Data

The data used in this study were interval level. Seawater temperature and A/C run-hours were derived from real-time ICAS data. These ICAS data were logged as ships operated in various environments. Similarly, cost data were interval level. All ships used in the research routinely reported actual corrective and preventative maintenance performed to NSLC.

C. ANALYSIS STRATEGY

1. Data Reduction

Derivation of A/C run-time hours and seawater temperature data from ICAS log entries required a computationally intensive algorithm. The goal of the data reduction process was to compute a daily tabulation of A/C run-hours and average seawater temperature for a given ship.

As previously stated, ICAS data were stored as a series of chronological log entries that was unsuitable for correlation analysis. Each ICAS entry used in the study consisted of the date and time of the log entry along with the corresponding seawater temperature for that time. Figure 4. shows the form of the ICAS data when downloaded in CSV format from MELS. As the figure shows, the log entries were not necessarily contiguous.

Date Time	Sea Water Inlet Temp
11/13/01 12:14	66
11/30/01 2:46	66
12/15/01 12:03	66
3/31/02 21:04	80
3/31/02 21:04	80
3/31/02 23:03	80
4/1/02 2:15	80
4/1/02 2:18	80
4/1/02 2:44	80
4/1/02 4:33	80
4/1/02 4:33	80
4/1/02 6:30	80
4/1/02 9:03	77
4/1/02 9:03	77

Figure 4. Sample of ICAS log data for FFG-7 class.

To calculate the daily run-hours for a given A/C plant, each day in the data range was divided into twelve equal segments of two hours each, beginning at 0000 and continuing to 0200, 0400 etc. The segmentation conformed to standard engineering practice aboard naval vessels, wherein logs were taken at designated fixed intervals of one or two hours and a new day of logs was always begun at 0000. ICAS log entries were then examined for corresponding entry times, taking precautions to remove duplicate or redundant entries from consideration. Because logs were only taken on

running equipment, a 0202 log entry indicated that the A/C plant was running at that time. If this entry was followed by a valid entry at time 0405, the machine was assumed to be running for the entire 0200-0400 time segment. However, if no valid entries were present for the 0600 time segment, then the A/C machine was assumed to have been secured during the 0400 to 0600 time segment. Simultaneously, an average seawater temperature for each day was calculated based on the ICAS entries for seawater inlet temperature. This daily average temperature was the arithmetic mean of the valid seawater inlet temperature log entries.

The above analysis was completed for one A/C plant at a time. The results of this data reduction for all the A/C plants aboard a single ship were collected in a format similar to Figure 2. . For all 24 ships included in the research, 4,282 days of data were produced using the described data reduction method. The results of the reduction are presented graphically in Appendix C. Similar data reductions were unnecessary for cost data.

A complete list of the 4,282 days of data produced by the above reduction algorithm could not be accommodated within this thesis. Therefore, the raw data will be available to inquiring scholars from the thesis advisor Professor William J. Haga, currently using wjhaga@nps.navy.mil, wjhaga@mbay.net and wjhaga@jackfire.net as e-mail addresses.

2. Pearson Correlations

a. Daily A/C Run-hours and Average Seawater Temperature

To determine the relationship between seawater temperature and A/C plant use, the Pearson correlation coefficient ($r^{temp,A/C\ hours}$) between the daily average seawater temperature and total A/C run-time hours for the same day was calculated for each ship included in the data pool. These values are shown in Figure 2. as “AVG SW TEMP” and “TOT HRS”, respectively.

An aggregate or class-wide correlation coefficient was also calculated by treating all of the daily data for a given ship class as if it were generated from a single ship. The resulting $r^{temp,A/C\ hours}$ was not simply the mean of the previously calculated

Pearson coefficients, but a separate statistical test of the class-wide correlation between A/C usage and seawater inlet temperature.

b. Maintenance Cost and A/C Usage

To measure the extent to which A/C usage is a significant maintenance cost driver, Pearson correlations ($r^{A/C\ hours,cost}$)were calculated for maintenance costs and A/C usage. These entering arguments are labeled in Figure 3. as "COST" and "HOURS", respectively. The calculation was performed for each ship included in the data pool. Unlike $r^{temp,A/C\ hours}$, $r^{A/C\ hours,cost}$ was calculated using monthly A/C usage hours and cost data. Monthly run-hours were calculated as the sum of all daily run-hours ("TOT HRS" in Figure 2) in that month.

As with A/C run-hours and seawater temperature, an aggregate or class-wide coefficient was calculated for maintenance costs and run-hours. This was done by treating all of the monthly cost and run-hour data as if it were generated by a single ship. As before, the calculated coefficient represents a stand-alone statistical test of whether a correlation between cost and A/C run-hours exists for a given ship class.

c. Elapsed Time and Maintenance Costs

To determine if A/C maintenance costs varied with time to any significant degree, maintenance costs were correlated against the time period over which the ICAS data for each ship was collected. These entering arguments are labeled in Figure 5. as "Cost Over Entire Period" and "Elapsed Time in Months", respectively. The time period was calculated as the inclusive date range of the available ICAS data for each ship, in months. Figure 5 shows the form of the entering arguments for the Pearson correlation of PERRY class frigate data. The resulting coefficient, $r^{time,cost}$, was calculated for TICONDEROGA and ARLEIGH BURKE class vessels using analogous input tables.

Ship	Elapsed Time in Months	Cost Over Entire Period
FFG A	10	$19,355
FFG B	10	$31,988
FFG C	6	$10,138
FFG D	10	$188
FFG E	19	$26,383

Figure 5. Sample output of entering arguments for time/maintenance cost correlation.

III. FINDINGS

A. STATISTICAL CALCULATIONS

1. Pearson Correlation

Pearson correlations measure the degree of linear association between two variables. The resulting coefficient, r, is a fraction that indicates the strength of the association. A value of –1 indicates a perfect negative association, while an r value of +1 indicates a perfect positive correlation. A calculated r with a value of 0 suggests that there is no association between the two variables being examined. Figure 6. illustrates the different types of association between variables.

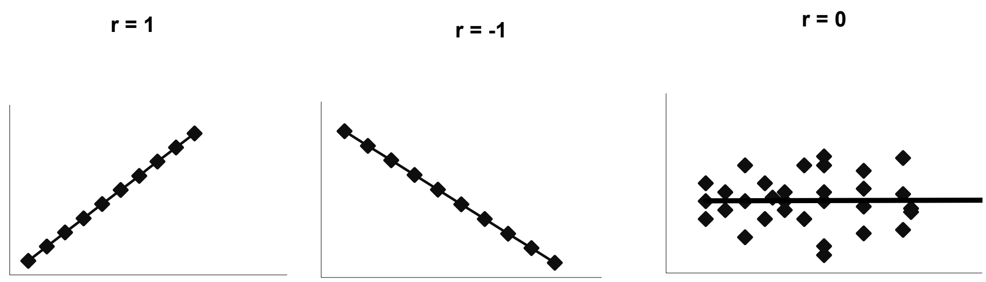

Figure 6. Illustration of types of association between variables

Correlation calculations test an underlying null hypothesis. For Pearson correlations, the null hypothesis is that no association exists between variables. Comparing the calculated p-value to the value of alpha tests the validity of the stated null hypothesis. If the p-value is less than alpha, the null hypothesis is rejected. If the p-value is greater than or equal to alpha, then the null hypothesis cannot be rejected. In the latter case, the inability to reject the null hypothesis confirms that there is no statistically significant association between the variables.

The alpha value indicates the level of uncertainty about the conclusion reached concerning the null hypothesis. A value of 0.10 says that the results are 90% certain, while a value of 0.15 corresponds to an 85% level of certainty. The alpha value chosen for this research was 0.05. This value corresponds to a 95% level of certainty about the

conclusion reached concerning the null hypothesis and is a standard value for academic research.

Correlation between variables may be classified as weak, moderate, or strong. For absolute values of r greater than or equal to 0.8, the strength of correlation is strong. A moderate association exists for absolute values of r less than 0.8 but greater than 0.5. Finally, for absolute values of r less than or equal to 0.5, only a weak association exists.

2. ANOVA Analysis

Analysis of Variance Analysis (ANOVA) is a method of comparing the means of multiple groups of numerical measurements. Because ANOVA compares the arithmetic means of numerical groups, the null hypothesis is that the means of all of these groups are equal. The alternate hypothesis states that there is a statistically significant difference between the means of the various numerical groups.

As with Pearson correlations, ANOVA yields a p-value that is compared to the chosen value of alpha to determine whether to accept or reject the null hypothesis.

B. A/C USAGE AND SEAWATER TEMPERATURE CORRELATION

Given that $r^{\text{temp,A/C hours}}$ is the population correlation coefficient for all naval vessels, then for all Pearson correlation calculations, the null hypothesis, alternate hypothesis, and alpha value (respectively) are as follows:

$$NULL : \mathrm{r}^{\text{temp,A/C hours}} = 0$$
$$H_1 \quad : \mathrm{r}^{\text{temp,A/C hours}} > 0$$
$$\alpha = .05$$

1. FFG-7 Class Frigates

Table 1. shows the correlation results for the OLIVER HAZARD PERRY (FFG-7) class frigates included in the research.

Ship	$r^{temp,A/C\ hours}$	p-value	Null Hypothesis
FFG-A	0.0180	0.8000	CANNOT REJECT
FFG-B	0.8430	0.0000	REJECT
FFG-C	0.5790	0.0000	REJECT
FFG-D	0.7980	0.0000	REJECT
FFG-E	0.5450	0.0000	REJECT
class-wide	0.6700	0.0000	REJECT

Table 1. Run-hour/seawater temperature correlation results for FFG-7 class.

The class-wide statistics show that for the FFG-7 class, there was a statistically significant correlation between A/C usage and seawater temperature. Using the language of the thesis model, seawater temperature is a significant driver of A/C plant usage for FFG-7 class ships.

2. CG-47 Class Cruisers

Table 2. gives the results of the correlation analysis for TICONDEROGA (CG-47) class cruisers used in the research.

Ship	$r^{temp,A/C\ hours}$	p-value	Null Hypothesis
CG-A	0.1660	0.1690	CANNOT REJECT
CG-B	0.4150	0.0000	REJECT
CG-C	0.5230	0.0000	REJECT
CG-D	0.5560	0.0000	REJECT
CG-E	0.4500	0.0000	REJECT
CD-F	-0.1240	0.3730	CANNOT REJECT
class-wide	0.0820	0.0230	REJECT

Table 2. Run-hour/seawater temperature correlation results for CG-47 class.

For the CG-47 class, the class-wide values of $r^{temp,A/C\ hours}$ and p-value indicated a statistically significant association between seawater temperature and A/C usage, although the relationship was relatively weak.

3. DDG-51 Class Destroyers

Table 3. lists correlation results for ARLEIGH BURKE (DDG-51) class destroyers used in the research.

Ship	$r^{temp,A/C\ hours}$	p-value	Null Hypothesis
DDG-A	0.4710	0.0000	REJECT
DDG-B	-0.0910	0.4660	CANNOT REJECT
DDG-C	0.1850	0.0170	REJECT
DDG-D	0.0360	0.5100	CANNOT REJECT
DDG-E	0.7260	0.0000	REJECT
DDG-F	-0.2190	0.0090	REJECT
DDG-G	0.8340	0.0000	REJECT
DDG-H	0.4270	0.0000	REJECT
DDG-I	0.3990	0.0000	REJECT
DDG-J	0.2790	0.0120	REJECT
DDG-K	0.8840	0.0000	REJECT
DDG-L	0.2720	0.0490	REJECT
DDG-M	0.2670	0.0510	CANNOT REJECT
class-wide	0.3570	0.0000	REJECT

Table 3. Run-hour/seawater temperature correlation results for DDG-51 class.

As with the FFG-7 and CG-47 class, the class-wide statistics for the DDG-51 class show a statistically significant association between A/C run-hours and seawater inlet temperature for ARLEIGH BURKE class destroyers.

C. A/C USAGE AND MAINTENANCE COSTS CORRELATION

As in the previous analysis, $r^{A/C\ hours,cost}$ is the population correlation coefficient. Then for all Pearson correlation calculations, the null hypothesis, alternate hypothesis, and alpha value (respectively) are as follows:

$$NULL : r^{A/C\ hours,cost} = 0$$
$$H_1 : r^{A/C\ hours,cost} > 0$$
$$\alpha = .05$$

1. FFG-7 Class Frigates

Table 4. displays the results of the maintenance cost/air conditioning usage analysis for FFG-7 class ships.

Ship	$r^{A/C\ hours,cost}$	p-value	Null Hypothesis
FFG-A	0.502	0.139	CANNOT REJECT
FFG-B	0.154	0.671	CANNOT REJECT
FFG-C	-0.174	0.553	CANNOT REJECT
FFG-D	0.382	0.276	CANNOT REJECT
FFG-E	0.005	0.991	CANNOT REJECT
class-wide	0.231	0.142	CANNOT REJECT

Table 4. Maintenance cost/run-hour correlation results for FFG-7 class.

The results displayed in Table 4. show that there was no evidence of a statistically significant association between A/C usage and maintenance cost for OLIVER HAZARD PERRY class ships.

2. CG-47 Class Cruisers

Table 5. displays the results of the maintenance cost/air conditioning run-hour analysis for CG-47 class ships.

Ship	$r^{cost,A/C\ hours}$	p-value	Null Hypothesis
CG-A	0.179	0.645	CANNOT REJECT
CG-B	-0.129	0.722	CANNOT REJECT
CG-C	-0.302	0.51	CANNOT REJECT
CG-D	0.944	0.215	CANNOT REJECT
CG-E	-0.516	0.104	CANNOT REJECT
CG-F	0.982	0.285	CANNOT REJECT
class-wide	0.205	0.187	CANNOT REJECT

Table 5. Maintenance cost/run-hour correlation results for CG-47 class.

These results show that there was no evidence of a statistically significant association between A/C usage and maintenance cost at the 95% confidence level for TICONDEROGA class ships.

3. DDG-51 Class Destroyers

Table 6. lists the results of the run-hour/maintenance cost correlation analysis for DDG-51 class vessels used in the research. DDG-K and DDG-M had insufficient cost data to support a correlation calculation.

Ship	$r^{cost,A/C\ hours}$	p-value	Null Hypothesis
DDG-A	-0.069	0.849	CANNOT REJECT
DDG-B	-0.267	0.428	CANNOT REJECT
DDG-C	0.441	0.321	CANNOT REJECT
DDG-D	0.305	0.233	CANNOT REJECT
DDG-E	-0.215	0.503	CANNOT REJECT
DDG-F	-0.641	0.17	CANNOT REJECT
DDG-G	-0.215	0.48	CANNOT REJECT
DDG-H	-0.229	0.394	CANNOT REJECT
DDG-I	0.142	0.737	CANNOT REJECT
DDG-J	0.547	0.543	CANNOT REJECT
DDG-K	*	*	*
DDG-L	-0.167	0.893	CANNOT REJECT
DDG-M	*	*	*
class-wide	-0.092	0.396	CANNOT REJECT

Table 6. Maintenance cost/run-hour correlation results for DDG-51 class.

As with the TICONDEROGA and OLIVER HAZARD PERRY class vessels, there was no evidence of a statistically significant association between A/C run-hours and maintenance costs for the ARLEIGH BURKE class.

D. ELAPSED TIME AND MAINTENANCE COSTS CORRELATION

Defining $r^{time,cost}$ as the population correlation coefficient for all naval vessels, the null hypothesis, alternate hypothesis, and alpha value (respectively) are:

$$NULL : r^{time,cost} = 0$$
$$H_1 \quad : r^{time,cost} > 0$$
$$\alpha = .05$$

Table 7. displays the results of the elapsed time/maintenance cost analysis for all vessels used in the research.

Ship	$r^{time,cost}$	p-value	Null Hypothesis
All FFG’s	0.446	0.451	CANNOT REJECT
All CG's	-0.069	0.897	CANNOT REJECT
All DDG's	0.602	0.038	REJECT

Table 7. Correlation results for time versus maintenance costs.

The results of this analysis were mixed. There was no evidence of a statistically significant relationship between elapsed time and maintenance costs for FFG-7 and CG-47 class ships. However, a statistically significant relationship did exist for the DDG-51 class.

E. ANOVA ANALYSIS

Let μ be defined as an arithmetic mean. Then μ_{FFG} is the mean of the individual FFG-7 class correlation coefficients, $r^{\mathrm{temp,A/C\ hours}}$. Similarly, μ_{CG} and μ_{DDG} are defined as the arithmetic means of $r^{\mathrm{temp,A/C\ hours}}$ for the CG-47 and DDG-51 class, respectively. Then, for the following ANOVA analysis, the null hypothesis, alternate hypothesis, and alpha value are as follows:

$$NULL : \mu_{FFG} = \mu_{CG} = \mu_{DDG}$$
$$H_A \quad : \mu_{FFG} \neq \mu_{CG} \neq \mu_{DDG}$$
$$\alpha = .05$$

Figure 7. displays the results of the ANOVA analysis. The statistics compare the mean $r^{\mathrm{temp,A/C\ hours}}$ for the FFG-7 class, CG-47 class, and DDG-51 class vessels.

One - way ANOVA : $r^{\mathrm{temp,A/C\,hours}}$ versus ship type

Analysis of Variance Table

Source	DF	SS	MS	F	P - value
ship type	2	0.187	0.093	0.93	0.412
Error	21	2.119	0.101		
Total	23	2.306			

Figure 7. ANOVA table for temperature/usage correlation coefficients, all classes.

The results of the ANOVA show that we cannot reject the null hypothesis. The mean temperature/usage correlation coefficients for the DDG-51 class, FFG-7 class, and CG-47 class were equal. Thus, there was no evidence to suggest that the ship classes operated A/C plants differently from one another.

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IV. DISCUSSION

A. A/C USAGE AND SEAWATER TEMPERATURE CORRELATION

1. Results

Twenty-four ships were used in this study. Of that number, six ships did not have a statistically significant association between A/C usage and seawater temperature. 18 ships did have a statistically significant association between A/C usage and seawater temperature. In addition, the class-wide statistics show that for CG-47, DDG-51, and FFG-7 classes there was a statistically significant association between these factors. The class-wide correlation values ranged between a moderately associative 0.67 for PERRY class frigates to a weakly associative 0.08 for the TICONDEROGA class. For three ships the calculated Pearson correlation coefficients were negative. Using the language of the thesis model presented in Figure 1. , the results show that seawater temperature (and hence air temperature) was a significant factor in determining A/C plant use.

2. Factors Affecting $r^{temp,A/C\ hours}$

Several factors may have contributed to the associative disparity among ships in a given class. One possibility was the existence of a learning curve for users of the ICAS system. Under this theory, shipboard users of ICAS initially encountered some difficulty in adjusting to the new technology and performed more logging errors than normal. As ships became acclimated to the new technology, logs became more accurate. The evidence that a learning curve played a role in the poor showings of the six ships would be apparent by a physical inspection of the Pearson correlation coefficients. Under this theory the ships with the most recent ICAS installation dates would, as a group, have lower values of $r^{temp,A/C\ hours}$. However, this was not the case. In fact, several ships that had very recent installation dates had among the highest values of $r^{temp,A/C\ hours}$. Thus, there was no evidence to suggest the existence of a learning curve for the ICAS system. Appendix D contains a list of ICAS installation dates for ships used in this study.

Another possible contributor to the associative disparity among ships within a class was an equipment casualty. Simply put, ships without statistically significant

correlation values may have been precluded from operating A/C plants as intended due to one or more severe casualties to the A/C plants. Although individual ships may have desired to operate more A/C plants as temperature rose, this was not possible because one or more plants were secured for repair. Evidence of this could be found from a visual inspection of the data as presented in Figure 2. The expected trend would be maximized use of any remaining A/C plants were a casualty to exist on one or more plants while seawater temperatures continued to increase. However, these trends were not identifiable in the data for the six vessels with statistically insignificant $r^{temp,A/C\ hours}$. There was no evidence to suggest that equipment casualties played a significant role in forming the correlation values.

Last, erroneous sensor readings or poor logtaking methods may have been significant contributors to the associative disparity. However, the ICAS data, like the manual log data that it replaced, was reviewed by the shipboard Chain of Command (CoC) prior to leaving the ship. These reviews were meant to identify erroneous log readings and abnormal trends in log readings that indicated either failing sensors or poor watchstanding practices. Under this regimen, individual log entries would not have been corrected ex post facto but would have remained as logged. However, the causes for the abnormal readings would have been speedily investigated and corrected, minimizing the impact of this factor.

B. A/C USAGE AND MAINTENANCE COST CORRELATION

1. Results

For all 24 ships used in the research, there was no statistically significant association between A/C usage and maintenance costs for the A/C plants. In addition, the class-wide statistics also failed to show a statistically significant association between these factors for the FFG-7, CG-47, and DDG-51 class vessels. Referring to the thesis model of Figure 1, the results show that A/C plant usage was not a significant driver of A/C plant maintenance costs.

2. Factors Affecting $r^{A/C\ hours,cost}$

Several aspects of the cost data used may have affected the results of the individual Pearson correlations. First, the NSLC cost data included both the cost of labor and the cost of parts. The total parts cost for a given month was a direct summation of the cost of individual parts used in that month based on the listed price of the items. In contrast, the labor costs were calculated by applying standard rates to the labor hours reported by each ship. The researcher's personal experience in this area has shown that the reporting of labor hours is inconsistent. Specifically, the individual workcenters that perform equipment maintenance do not maintain accurate and continuous logs that track labor hours spent on ongoing maintenance actions. Instead, labor hours are recorded after the maintenance action is complete, based on the best estimate of the workcenter. In most cases this leads to over or underestimating the actual labor hours spent on an individual maintenance action. However, this recording methodology is standard practice throughout the fleet and would therefore have affected all vessels in this study equally. There was no evidence to suggest that any one ship in the study was affected more by this practice than others.

Next, maintenance actions are at times postponed due to operational restrictions. This is true of both preventative actions and corrective maintenance actions. Intermediate level maintenance, in particular, is prone to lengthy delay due to budgetary and operational considerations (Emerson, 2001). In many cases these delays prove significant, leading to a relatively lengthy time period between the onset of the need for maintenance and the performance of that maintenance with requisite recording of associated costs. Delays are normally not standard but are implemented on a case by case basis. However, as with labor costs, there was no evidence to suggest that any one vessel was affected more severely by this practice than others in the same class. In addition, the majority of listed costs for each vessel were for Organizational level parts and labor.

C. ELAPSED TIME AND MAINTENANCE COST CORRELATION

1. Results

For the three ship classes examined using this correlation, only the DDG-51 class vessels displayed a statistically significant association between elapsed time and maintenance costs. For the BURKE class, the association was moderate, 0.60. This result showed that for the ARLEIGH BURKE destroyers, maintenance costs had a moderate dependence on time, but not on A/C usage. While a similar relationship cannot be ruled out for the TICONDEROGA and PERRY class vessels, there was insufficient evidence to establish the association.

2. Factors Affecting $r^{time,cost}$

A perfunctory scan of the maintenance cost data presented in Figure 3. shows that there are months when reported costs are zero. For some vessels this trend was more pronounced. This phenomenon had the effect of setting the cost baseline for any month equal to zero and was observed in the data for all three classes used in the research. There was no evidence to suggest that the trend affected the DDG-51 class differently than the CG-51 and FFG-7 class vessels.

D. ANOVA ANALYSIS

The ANOVA analysis examined the relationship between the means of the ship correlation coefficients, $r^{temp,A/C\ hours}$. This analysis compared the mean correlation coefficients of one ship class to another ship class, but did not compare coefficients within a ship class. The results show that there was no significant difference between the mean correlation values of FFG-7, DDG-51, and CG-47 class ships. This finding implies that despite differences in hull configuration and operating characteristics, the three ship classes, on average, had the same increase in A/C usage with a rise in seawater temperature.

V. CONCLUSION

A. SUMMARY

Naval vessels now routinely operate in regions with severe weather environments. In areas such as the Arabian Gulf, air temperatures regularly exceed 95 degrees (F) and water temperatures can exceed 90 degrees in the summer months. The proper functioning of shipboard A/C plants is of keen interest to any person who has served in that region. Identifying a relationship that describes the association between air or seawater temperature, A/C plant use, and maintenance costs would prove valuable in the planning of maintenance budgets. The process of identifying such a relationship has been simplified by the availability of ICAS and NSLC data. Using these sources, this research showed that seawater temperature is a statistically significant driver of A/C plant usage. However, A/C plant usage, in turn, is not a statistically significant driver of A/C plant maintenance costs.

In projecting maintenance costs for shipboard A/C plants, elapsed time appears to play a more substantial role than A/C plant use. Perhaps this may be due to the nature of the PMS system, with schedule-driven maintenance requirements based on calendar dates. A majority of the A/C plant maintenance costs for the ships in this study were for Organizational level maintenance.

B. RECOMMENDATIONS

The ICAS data used in this study provided the previously unavailable capability to obtain large amounts of engineering log data from operating fleet units. Although ICAS was originally intended to foster a shift towards Condition Based Maintenance (CBM) and not for the examination of cost/use relationships, the correlation methodology used in this research can be applied to a broad range of shipboard systems for which ICAS data is available. Identification of the major cost driver elements in systems such as main engines, turbine generators, propulsion gear, and freshwater distillation plants may improve future budgeting estimates for required Operations and Maintenance costs.

The researcher hopes that ICAS data will continue to be used for purposes outside its original scope.

An improved estimate of labor hours spent on maintenance actions may prove helpful for future research. This estimate could be derived from a study of ships operating in identical environments over a four to six month period, where labor hours would be carefully documented and continually updated as work was progressing, instead of reporting an estimate of labor hours at work completion. However, the gains from this effort would be minimal while the effort required would prove substantial.

Each A/C refrigeration system for a DDG-51 class ship costs the Navy roughly $2 million (Morrison, 2002), about evenly divided between system cost and installation cost. Altogether, the newly installed A/C plants represent about eight tenths of one percent of the total vessel cost. This fact, together with the finding that A/C maintenance costs do not appear to vary with plant use, discourages further research into this area.

LIST OF REFERENCES

Chief of Naval Operations
1994 OPNAVINST 4790.4C, *Ship's Maintenance and Material Management (3-M) Manual,* Office of the Chief of Naval Operations.

Chief of Naval Operations
2000 Naval Message DTG 061903Z JUL00, *3rd Quarter Announcement of Remaining FY00 and Tentative FY01 SHIP and Aircraft Decommissionings*, Chief of Naval Operations code N8, July 6, 2000.

Chief of Naval Operations NTP S-30-0001
2001 NTP S-30-0001, *Navy System Training Plan: Integrated Condition Assessment System (ICAS)*, Office of the Chief of Naval Operations, January 2001.

Commander Naval Surface Forces Atlantic
1999 Naval Message DTG 221455Z SEP99, *Integrated Condition Assessment (ICAS) Program Policy*, Commander Naval Surface Forces Atlantic (COMNAVSURFLANT) code N434A31, September 22, 1999.

Commander Naval Surface Forces Pacific
2001 Naval Message DTG 261044Z MAR01, *Integrated Condition Assessment (ICAS) Program Policy*, Commander Naval Surface Forces Pacific (COMNAVSURFPAC) code N00, March 26, 2001.

Emerson, Bradley E.
2001 *Maintenance Trend Analysis of Air Conditioning Systems for Ship Operations in the Arabian Gulf,* Naval Postgraduate School Thesis, December 2001.

Krooner, Ken
2002 Phone conversation between the researcher and Ken Krooner, ICAS technician, Naval Sea Systems Command Philadelphia, July 18, 2002.

Leonard, James
2002 Phone conversation between the researcher and James Leonard, ICAS Coordinator, Fleet Technical Service Support Center Atlantic (FTSCLANT), July 26, 2002.

Morrison, Robert
2002 Phone conversation between the researcher and Robert Morrison, Naval Sea Systems Command (NAVSEA) Code 9213 A/C Refrigeration, August 7, 2002.

Naval Sea Center for Logistics ICMP
2002 URL: https://nslcweb2.navsea.navy.mil/Icmp/SilverStream/Pages/fsIcmpHomePage.html, *Integrated Class Maintenance Plan Homepage,* September 10, 2002.

Naval Sea Center for Logistics HEDRS
2002 URL: https://nslcweb2.navsea.navy.mil/Utilities/pgLogin.html?app=6093, *Hull, Mechanical, and Electrical Equipment Data Research System (HEDRS) Website,* October 2, 2002.

Naval Sea Center for Logistics SMCM
2002 URL: https://nslcweb2.navsea.navy.mil/Metrics, *Navy Ship Material Condition Metrics Website,* September 14, 2002.

Naval Sea Systems Command
2002 URL: https://icas.navsses.navy.mil/, *Integrated Condition Assessment System Homepage*, October 2002.

Surface Warfare Division (N76)
2002 URL: http://surfacewarfare.nswc.navy.mil/n76/ddg51.html, *Surface Warfare Division DDG-51,* Office of the Chief of Naval Operations, Surface Warfare Division (N76), October 8, 2002.

BIBLIOGRAPHY

Berenson, Mark L. and David M. Levine
1999 *Basic Business Statistics: Concepts and Applications*. Upper Saddle River: Prentice Hall.

DiUlio, Michael R.
2002 Telephone conversation between the researcher and Michael DiUlio, NAVSEA Code 05Z53 Special/Smart Projects Officer, Washington D.C., August 5, 2002.

Green, Bruce
2002 Telephone conversations between the researcher and Bruce Green, NAVSEA Philadelphia Code 9521, Philadelphia, PA, August 2002.

Lienbach, Russell A.
2002 E-mail correspondence between the researcher and Russell Lienbach Jr., NAVSEA Philadelphia Code 9521.2, Philadelphia, PA, July 22, 2002.

Revelas, Stephen K.
2001 *Reconstitution Costs of Aircraft Launch and Recovery Equipment Due to Contingency Operations,* Master's Thesis in Management, Naval Postgraduate School, Monterey, CA, June 2001.

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APPENDIX A: LIST OF ACRONYMS

A/C	Air Conditioning
APL	Allowance Parts List
CBM	Condition Based Maintenance
CSMP	Current Ship's Maintenance Plan
CSV	Comma Separated Value
EIC	Equipment Identification Code
FTSCLANT	Fleet Technical Support Center Atlantic
FTSCPAC	Fleet Technical Support Center Pacific
HEDRS	Hull, Mechanical, and Electrical Equipment Data Research System
ICAS	Integrated Condition Assessment System
MELS	Maintenance Engineering Library Server
NSLC	Naval Sea Center for Logistics
O&M	Operations and Maintenance
OPAREA	Operating Area
PMS	Planned Maintenance System
SMCM	Ship Material Condition Metrics
TYCOM	Type Commander

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APPENDIX B: ALLOWANCE PARTS LIST (APL) NUMBERS

Ship Class	A/C plant No. 1	A/C plant No. 2	A/C plant No. 3	A/C plant No. 4
CG-47	325010440 325010486	325010440 325010486	325010440 325010486	325010440 325010486
FFG-7	325000423E	325000423E	325000422E	*
DDG-51	325010478 32A000044	325010480 32A000047	325010479 32A000044	325010478 32A000044

* FFG-7 class has three A/C plants

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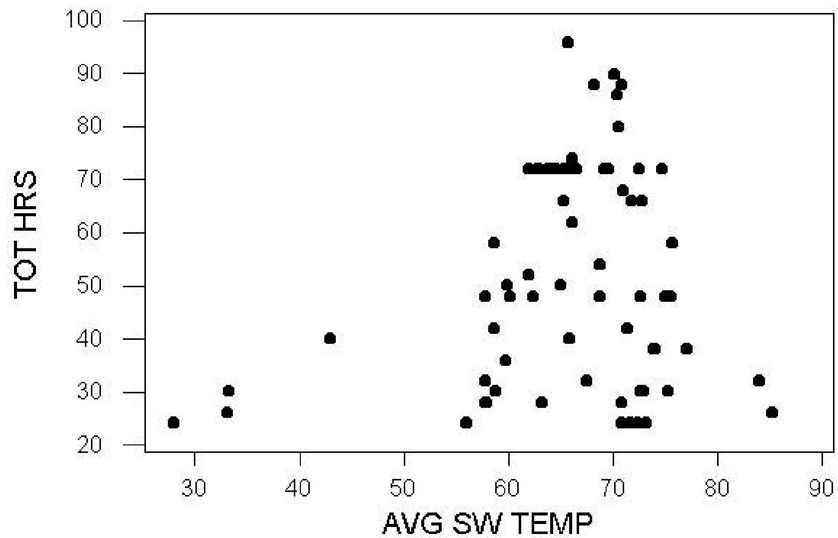
APPENDIX C: DATA PLOTS

CG-A



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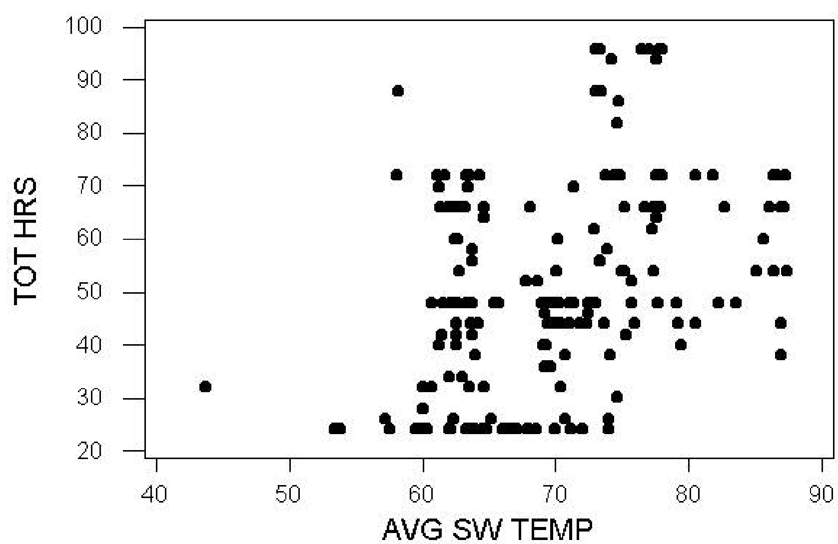

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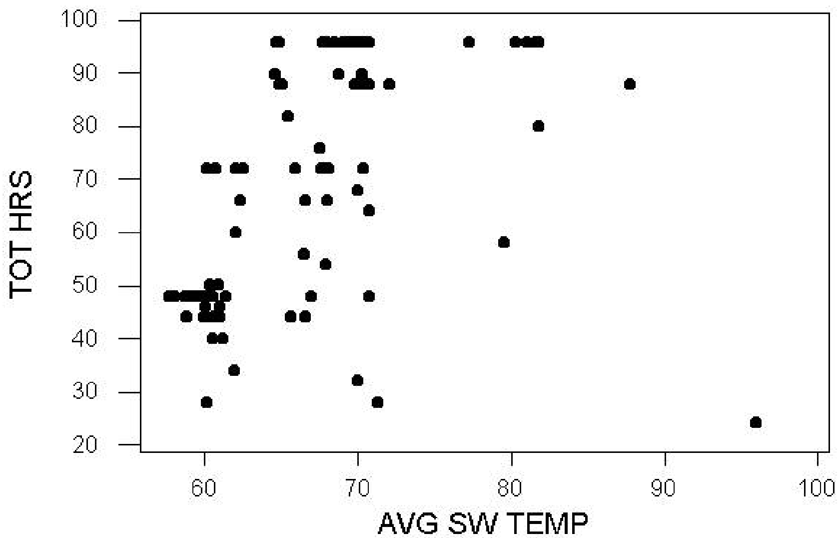
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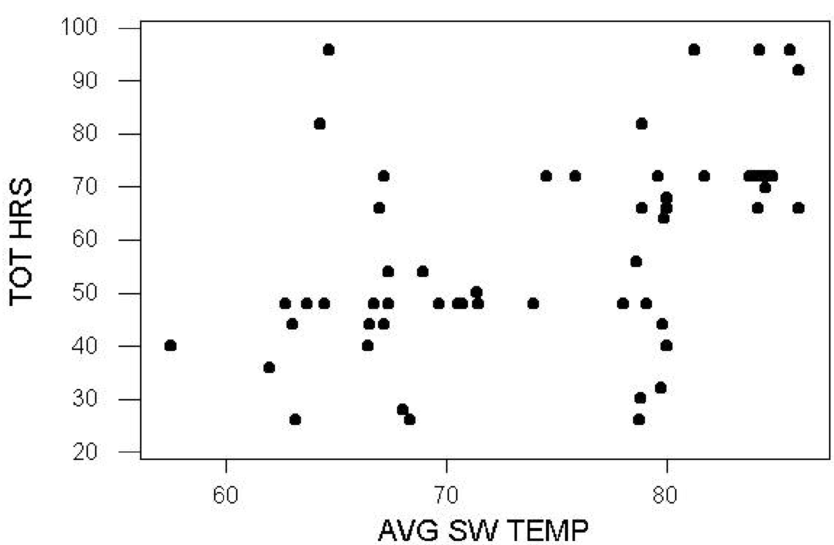
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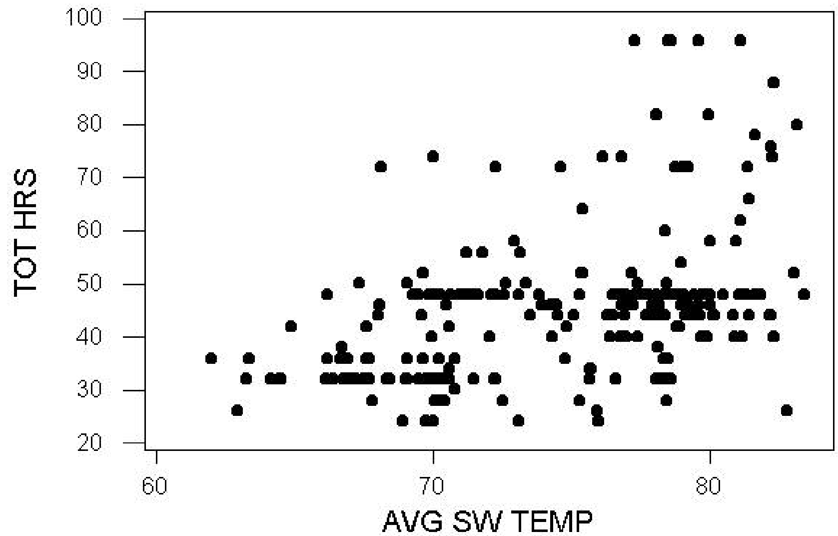
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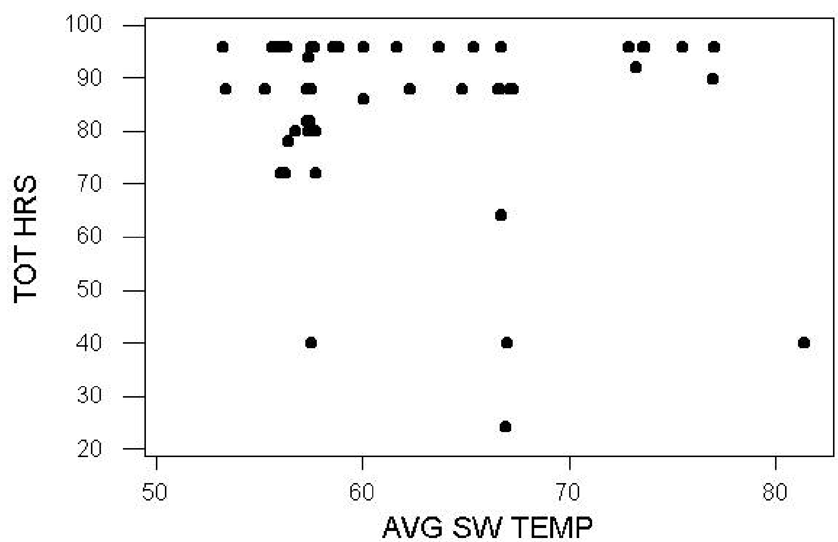
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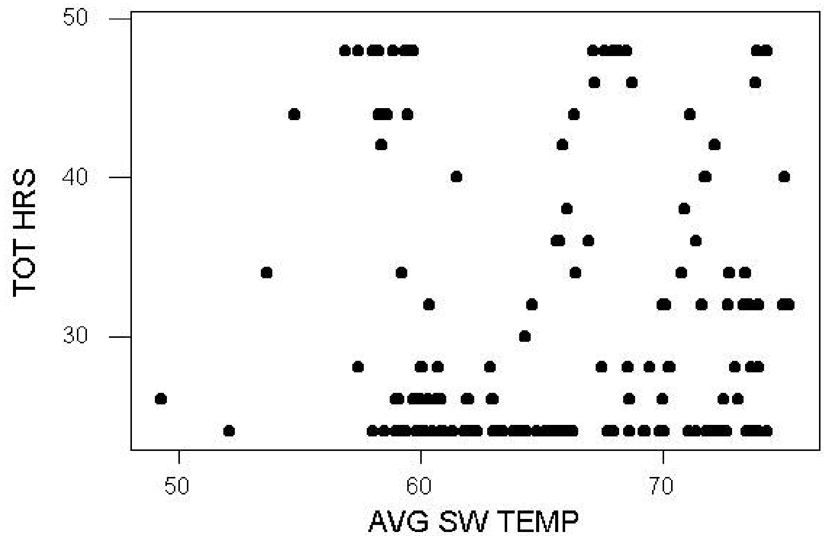
FFG-A



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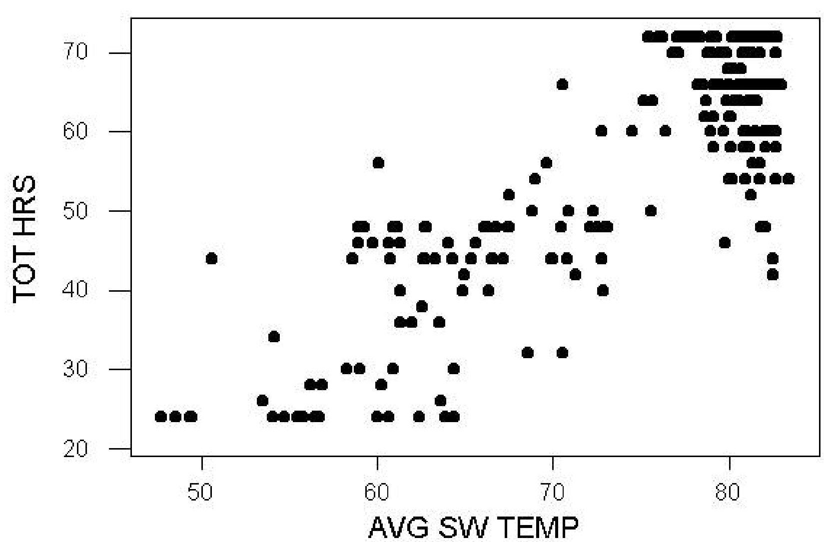
FFG-B



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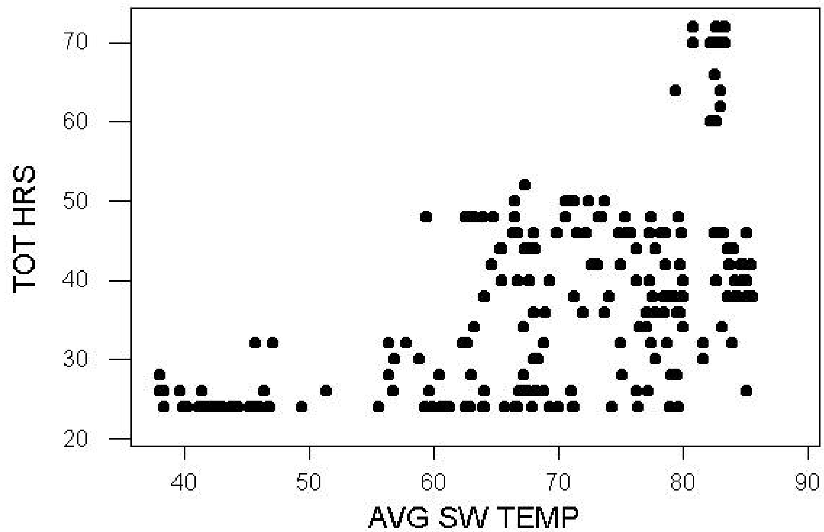
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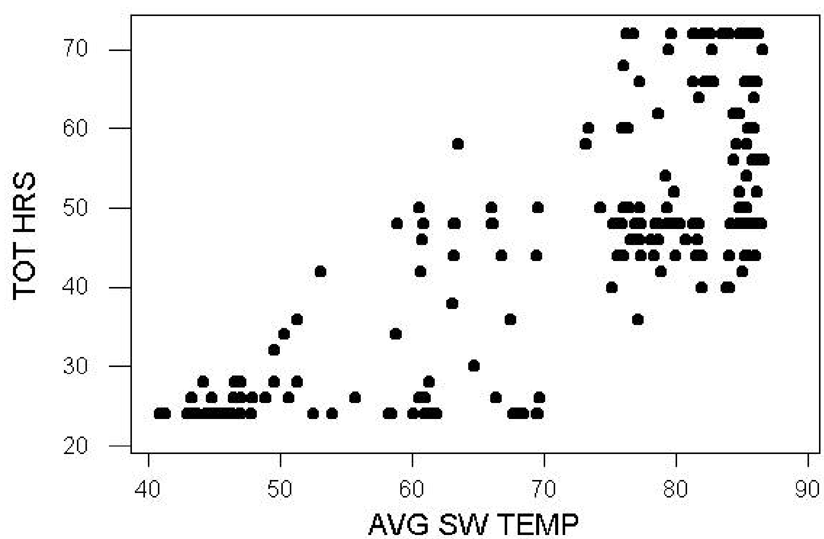
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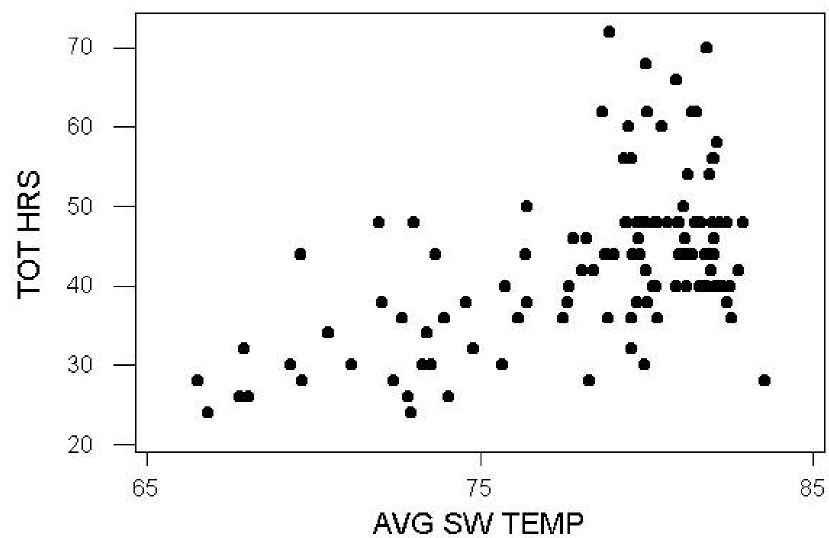
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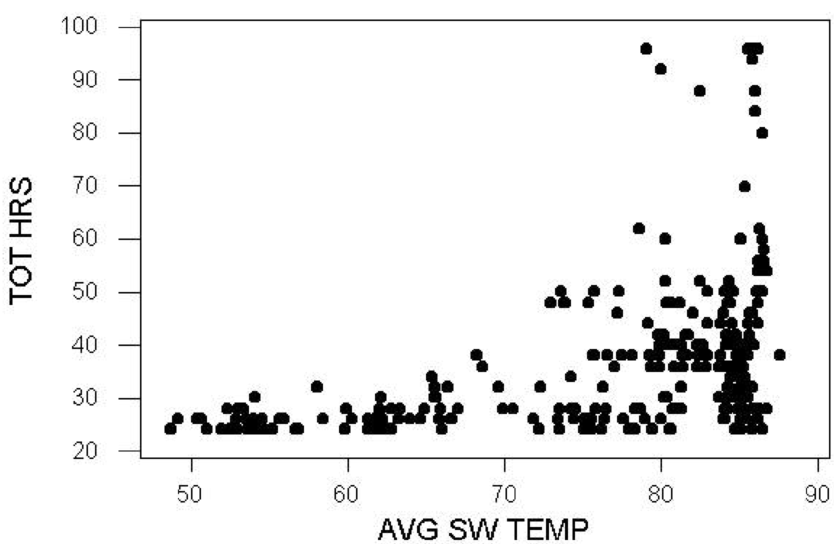
AVG SW TEMP

DDG-A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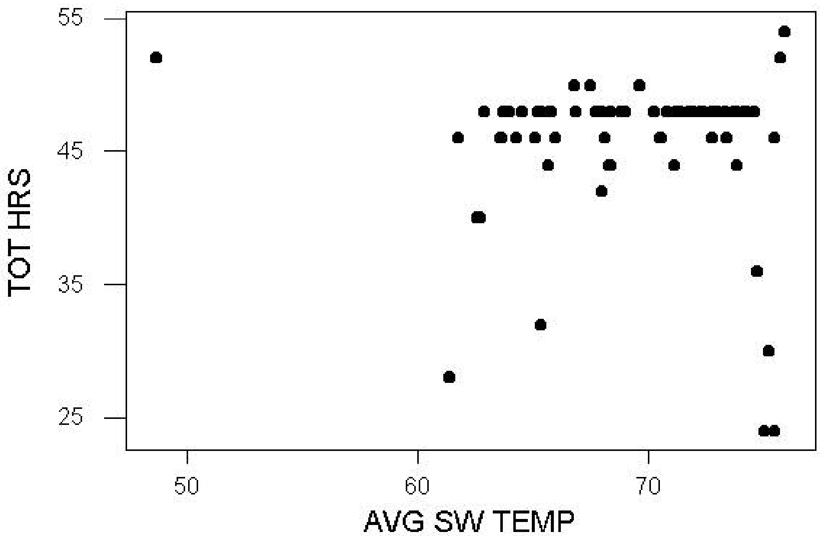
AVG SW TEMP

DDG-B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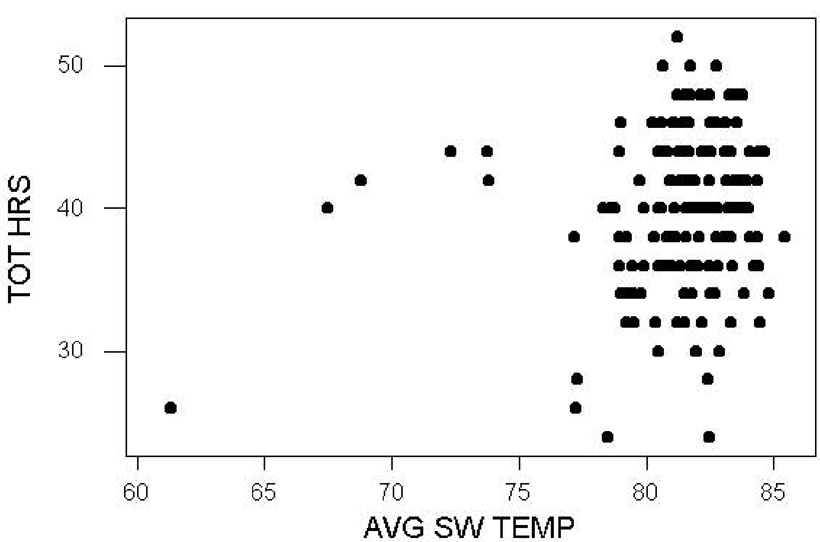
DDG-C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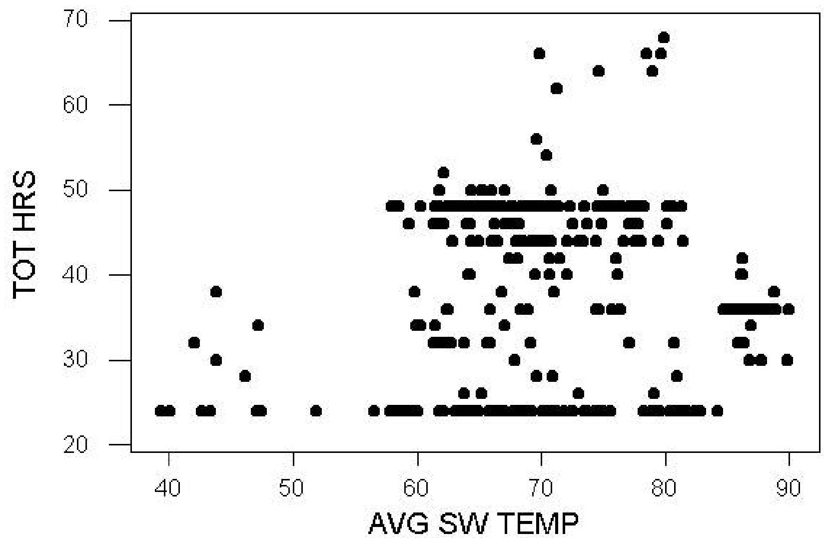
AVG SW TEMP

DDG-D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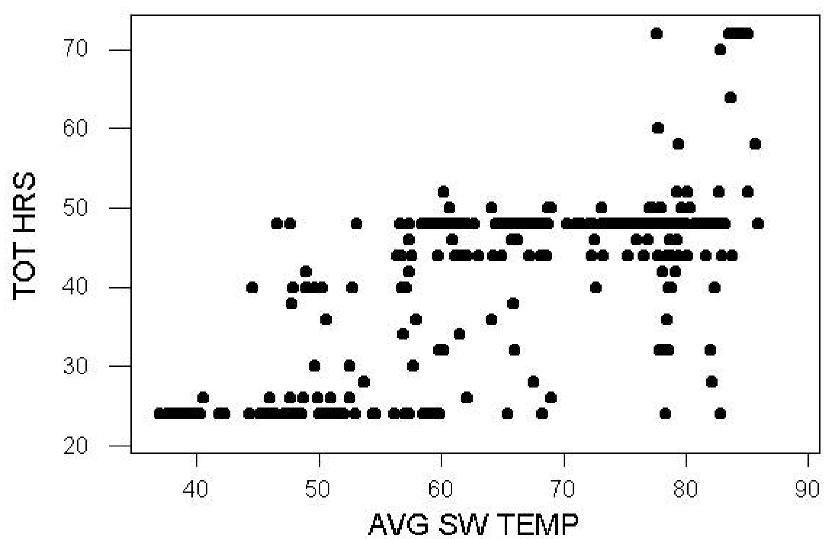
90

DDG-E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AVG SW TEMP
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30
40
50
60
70
40
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60
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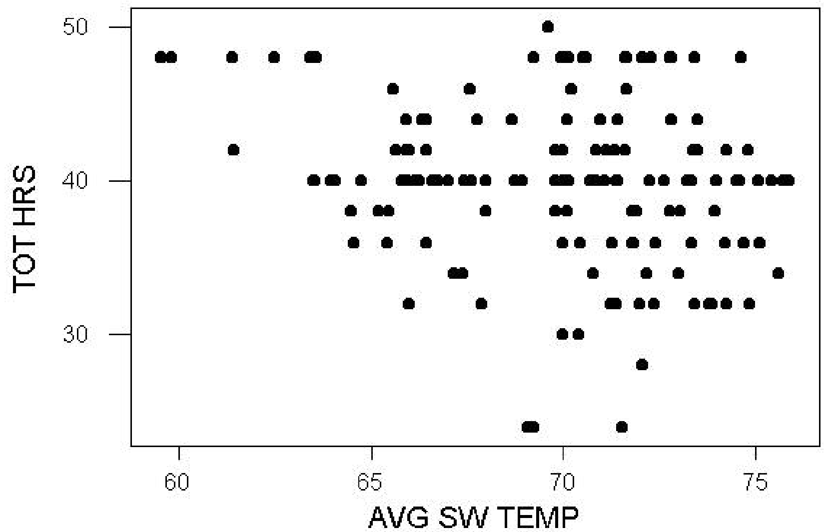
80
90

DDG-F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TOT HRS
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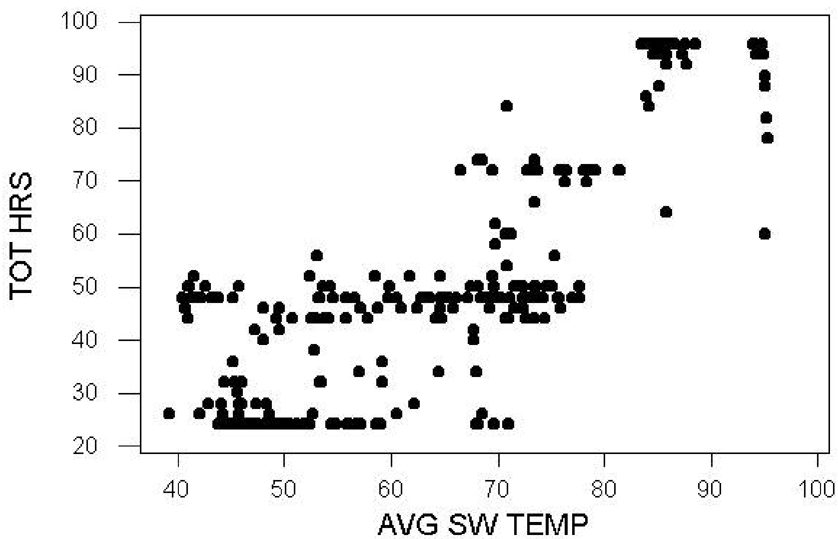
65
70
75
AVG SW TEMP

DDG-G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40
30
20
TOT HRS
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50
60
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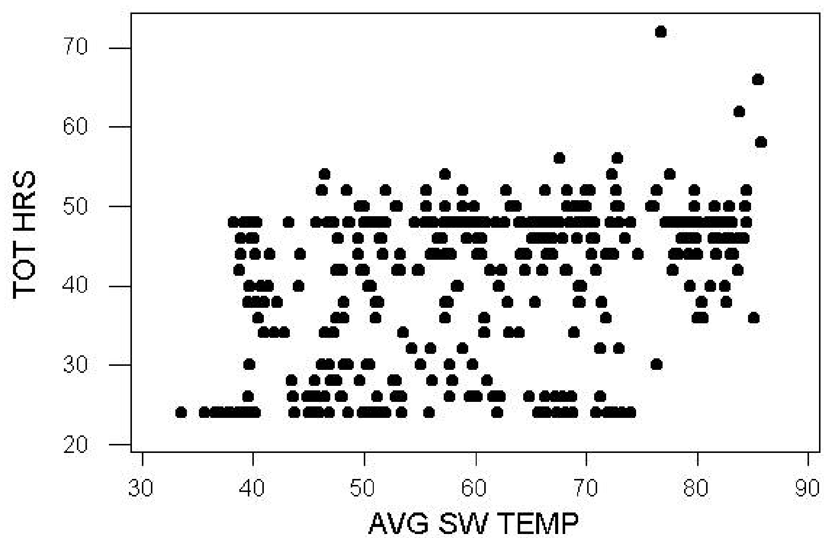
80
90
100
AVG SW TEMP

DDG-H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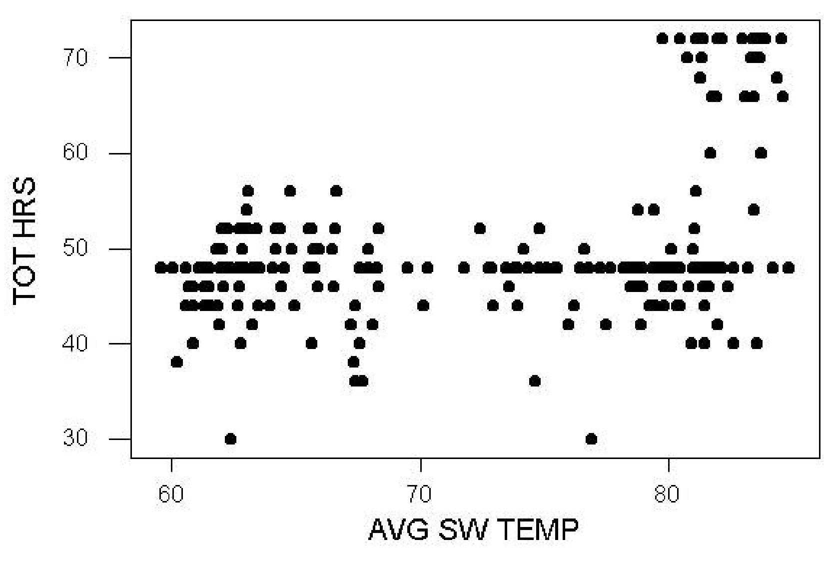
30
40
50
60
70
80
90

DDG-I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AVG SW TEMP
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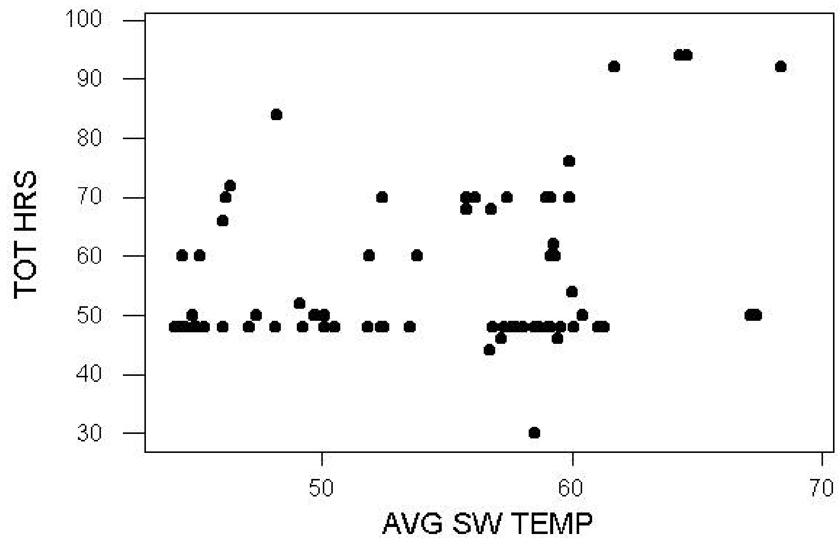
DDG-J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30
TOT HRS
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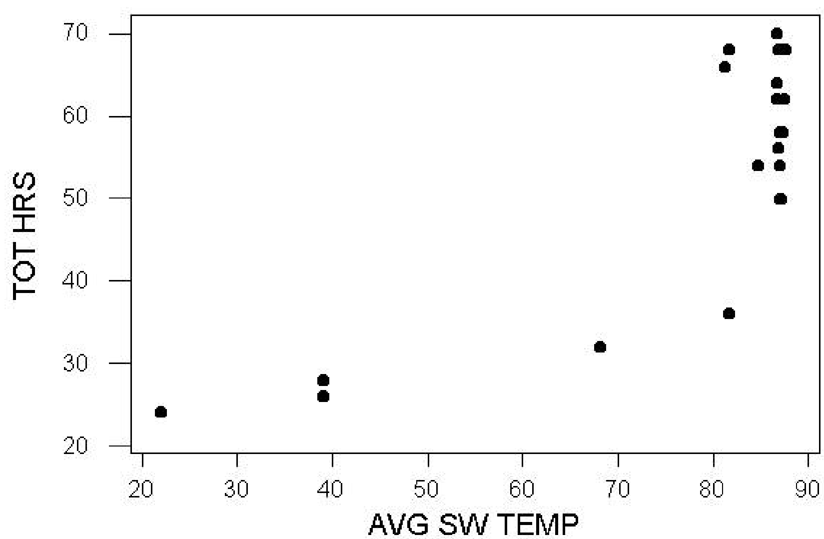
70
AVG SW TEMP

DDG-K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30
20
TOT HRS
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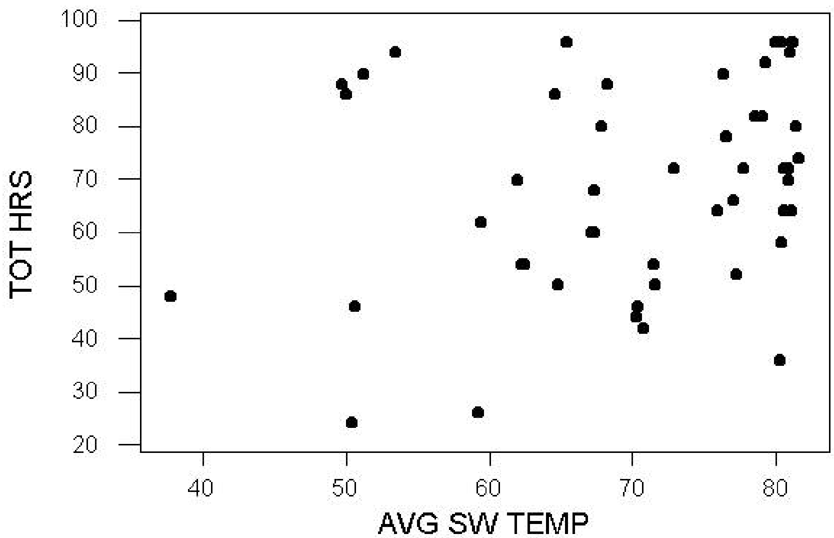
30
40
50
60
70
80
90
AVG SW TEMP

DDG-L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AVG SW TEMP
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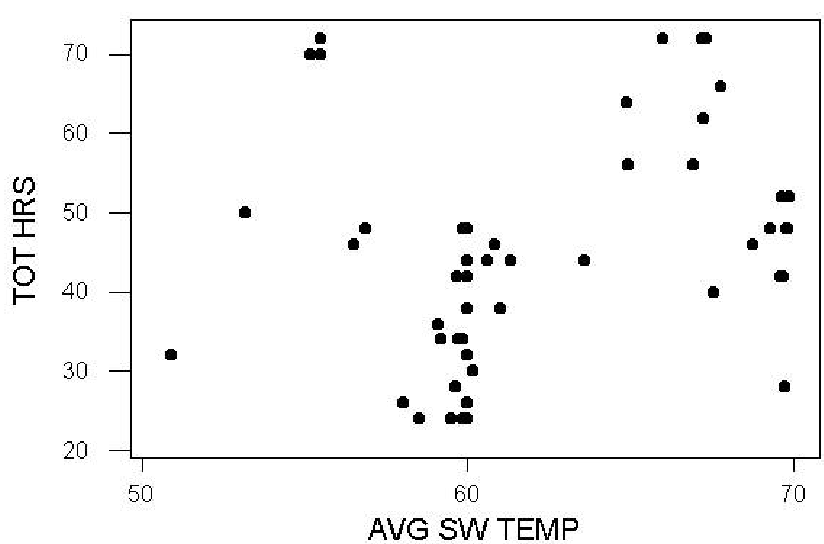
DDG-M


TOT HRS
AVG SW TEMP
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60
50
40
30
20
50
60
70

APPENDIX D: ICAS INSTALLATION DATES

Ship	Installation Date
FFG A	19-Jul-01
FFG B	10-Dec-00
FFG C	17-May-01
FFG D	26-Mar-01
FFG E	30-Apr-01
CG A	9-Mar-02
CG B	11-Jun-02
CG C	7-Jun-01
CG D	19-Jul-02
CG E	16-Jul-01
CG F	14-Apr-00
DDG A	1-Dec-00
DDG B	23-Aug-02
DDG C	3-Mar-00
DDG D	27-Dec-00
DDG E	23-Aug-01
DDG F	15-Aug-00
DDG G	29-Nov-00
DDG H	26-Jun-00
DDG I	10-Oct-00
DDG J	17-Oct-01
DDG K	14-Mar-02
DDG L	2-Jan-02
DDG M	2-Jan-02

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